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Changes in the Zooplankton Community in Response to Reductions in Nutrient Loading to Saginaw Bay (Lake Huron)

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16. ABSTRACT

Saginaw Bay (Lake Huron) receives tributary waters from the industrial heartland of Michigan. For twenty years University scientists have examined its water chemistry, physical characteristics including currents, and the community composition of its biota. This large amount of background information has permitted interpretation of the EPA's efforts to improve water quality in the system by diverting nutrients as phosphorus and nitrogen.

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1. INTRODUCTION

1.1 The reduction and eventual control of the rate of eutrophication of bays and inshore areas of the Great Lakes is of concern to the U.S. Environmental Protection agency. The 1978 Water Quality Agreement between the United States and Canada was designed "to restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem." Furthermore, Canada and the United States agreed "to eliminate or reduce to the maximum extent practicable the discharge of pollutants into the Great Lakes Ecosystem," which includes Saginaw Bay, Lake Huron.

Between 1974 and 1980 a natural experiment was conducted on the Saginaw Bay ecosystem. One aspect of this experiment involved an analysis of the impact of nutrient reductions upon the abundance and species composition of zooplankton in the Saginaw Bay system.

Fluvial inputs of total phosphorus to Saginaw Bay were greatest during 1975, with a targeted 50 percent reduction by 1978 (Dolan and Clark, 1979). By 1978 these fluvial loadings were cut by 50 percent of 1975 levels, chiefly by controlling the Saginaw River contribution. Previously, we (McNaught, 1975) hypothesized a graduate shift from the eutrophic indicator Bosmina longirostris to the more oligotrophic zooplankter (Diaptomus sicilis), based upon this magnitude of phosphate reduction.

Modelling phytoplankton growth in Saginaw Bay has demonstrated through validation, that specific nutrients have become more limiting as depletion occurs; nitrogen in the bay became more limiting to the phytoplankton crop post diversion (Bierman and Dolan, 1981). At the same time, the amount of phosphorus available determined the size of

the blue-green component of this community. Likewise during the predominant summer growth period, recycle of phosphorus from sediments was more important than external loadings. This finding suggested that the response of phytoplankton and zooplankton to nutrient diversion may be slower than expected.

The major purpose of this investigation was to document the pre-diversion abundance and composition of the zooplankton of Saginaw Bay, and to contrast that community with the post diversion community. Such a goal suggests that both static observations and measures of the speed of response to nutrient diversion are important.

1.2 Case histories of nutrient diversion

The result of nutrients diverted from Saginaw Bay on that ecosystem may best be anticipated through brief review of the results and successes/failures of similar programs. The kinds of data collected and important concepts ignored are evident from studies on Lake Monona (Wisconsin), Lake Washington, and the case studies of the U.S. International Biological Program.

The productivity of aquatic ecosystems is controlled from below by nutrient availability and solar radiation, and from above through grazing and predation by zooplankton and fishes. Basically both nutrient availability and grazing determine algal abundance and composition. Therefore, to understand the social and economic effects of nutrient diversion, we must examine both the response by algae and zooplankton (McNaught and Buzzard, 1973). In the current literature we find good examples of the response of the phytoplankton assemblage of a given system to nutrient withholding, but few examples of the concurrent response of the zooplankton community.

Lake Monona: An example of the effect of nutrient diversion upon a small aquatic system.

Residents living around Lake Monona (Madison, Wisconsin) complained as early as the early 1900's about nuisance algal blooms and scums. In 1912 the city attempted the first application of copper sulfate to control nuisance algae, apparently with some success. Diversion of nutrients, the logical answer to controlling blooms, was not attempted until 1936. During the war years (1941-45) some sewage was again dumped into the lake. From 1962 until the present, large blooms of algae have continued to occur, but these natural blooms lack scum-forming species of algae. The interactions between changing algal composition and quality and abundance were not examined (Edmondson, 1969).

Lake Washington: The most complete example of ecosystem effects of nutrient diversion.

The lands surrounding Lake Washington (Seattle, Washington) were cleared and settled in 1840. The lake received untreated sewage until 1930. In 1940, with construction of plants for wartime airplane construction, treated sewage was again dumped. By 1952 ten treatment plants were in operation. By 1957 the lake water contained twice the total phosphorous it had in 1930. Maximum enrichment was present during the years 1963-66. In 1967, sewage was diverted at a cost of $121 million to Puget Sound (Edmondson, 1969). By 1971, the total phosphorus had declined to 10 percent of that found in 1962, while nitrate was 20 percent and chlorophyll 40 percent of 1962 values.

Changes in dominant phytoplankton species were noted during the period 1930 to the present. A spectacular bloom of the blue-green algae Oscillatoria rubescens occurred during 1955. By 1962 algal abundance

had reached levels 15 times those of 1950. This increased algal productivity led to a low in hypolimnetic dissolved oxygen of 3 ppm in 1957 (Stockner and Benson, 1967). By 1964 so much sewage had been delivered to the lake that nitrogen had replaced phosphate as the limiting nutrient (Edmondson, 1969).

Changes in dominant zooplankton of Lake Washington are more difficult to document. During the period October 1949 through October 1950, approximately six treatment plants were discharging to Lake Washington. Thus, the system was receiving increasing amounts of nutrients but had not reached the levels of insult that were to come (1963-66). Generally in examining the zooplankton fauna of North American lakes, the certain of calanoid copepods are our best measure of oligotrophic conditions. In the year beginning October 1979, the calanoid copepod Diaptomus ashlandi fed and reproduced (January through July) on diatoms produced during the spring bloom (March through June). This spring bloom consisted early predominantly Cyclotella bodanica and during its later stages of Fragillaria crotenensis, Melosira varians, and Stephanodiscus niagarae. Apparently the pulse of calanoid reproduction was in cycle with diatom productivity (Table 1). Similarly, 40 years earlier in the history of the lake (1933-34), Scheffer and Robinson (1939) had noted a similar dependence of Diaptomus ashlandi on diatoms. Comita and Anderson (1959) even noted that the later copepodite stages took exceptionally long periods to develop if diatoms were not present in abundance.

Lake Wingra

The sources, loading, and fate of phosphorus and nitrogen were examined for Lake Wingra (Madison, Wisconsin) during the International Biological Program. These data strongly suggest that the reduction

TABLE 1. Comparison of zooplankton growth versus diatom abundance in Lake Washington (from Comita and Anderson 1959).

	Month					
	Jan	Feb	Mar	April	May	June
Density of Phytoplankton						
Cyclotella	-	-	71	464	332	210
Fragillaria	-	-	1	14	86	215
Melosira	-	-	-	44	69	7
Stephanodiscus	-	-	-	1,497	125	-
Zooplankton Activity						
Sexually active	----------			peak	----------	
Egg production	peak	peak	peak	----------		
Naupliar growth	----------		peak	peak	peak	--------

TABLE 2. PERCENTAGE LOADING OF AND OUTFLOW OF PHOSPHORUS AND NITROGEN BY SOURCE TO LAKE WINGRA (FROM LIKENS AND LOUCKS, 1978)

	Phosphorus	Nitrogen
Inputs		
Precipitation		
Dissolved	1	3
Particulate	9	7
Litter	<1	<1
Fluvial		
Dissolved	49	67
Particulate	40	11
Losses		
Fluvial		
Dissolved	5	13
Particulate	7	5
Insect Emergence	1	1
Sedimentation	87	55
Denitrification	NA	26

in fluvial loading (in the case of Saginaw Bay, primarily Saginaw River at 93 percent) to Saginaw Bay will solve the problem of accelerated eutrophication, as fluvial loading constitutes the major factor for most lakes (Table 2).

Conclusions for Case Histories

Fluvial inputs of phosphorus and nitrogen are chiefly responsible for the cultural eutrophication of many lakes. Similar studies are also underway on the Potomac estuary (Jaworsky, 1979). A significant reduction in total nutrient loading is best accomplished by reducing fluvial inputs. Such inputs to Saginaw Bay already have been reduced 50 percent. In Lakes Monona and Washington blooms of nuisance algae were later reduced following diversion of nutrients; in Lake Washington chlorophyll levels fell 60 percent, a truly astounding amount, and phosphorus was no longer the limiting (stimulating) nutrient to the ecosystem.

Published data do not include information on the recovery of zooplankton populations following reductions in loading; thus the following results add a new dimension to understanding the recovery of perturbed aquatic ecosystems.

2. CONCLUSIONS

The U.S. Environmental Protection Agency, in an attempt to reduce pollution and maintain the biological integrity of Saginaw Bay (Lake Huron), reduced fluvial inputs of phosphorus by 50% between 1975 and 1978. By 1980 this action had resulted in a 24% decrease in available orthophosphate for phytoplankton growth.

The zooplankton community of Saginaw Bay relies on algal and detrital foods (McNaught et al. 1981). A reduction in phosphorus loading of 50% resulted in significant changes in this community. The crustacean zooplankton were moderately reduced in abundance. Total crustaceans fell from a yearly mean of 155700/m^3 in 1974 to 97800/m^3 in 1980. The percentage composition of the eutrophic indicator Bosmina longirostris remained however realtively constant at 38%. A slight indication that populations of the oligotrophic indicator Diaptomus sicilis were increasing in the Bay was presented.

The rotiferan zooplankton responded to nutrient diversion very dramatically. Total rotifers decreased significantly between 1974 and 1980, experiencing approximately a 3-fold reduction. Likewise, predatory rotifers decreased significantly, an indication that one of the apex groups of organisms had responded as predicted to nutrient limitation, in a similar fashion that an apex fish predator would be encouraged by a decrease in toxic substances.

Variations in zooplankton crops in Saginaw Bay within and between years were attributed to variations in the flow of the Saginaw River. Care was taken to account for this fact in attributing a significant improvement in the Bay's water quality to nutrient diversion.

3. RECOMMENDATIONS

The improvement of the water quality in any ecosystem as large as Saginaw Bay is a challenge because of the nutrients and complex food webs involved. Initial indications from the costly diversion of nutrients to Saginaw Bay in 1978 suggest that the experiment is working. The tools of the field ecologist, however, are not sharp enough to reach a firm conclusion after only one year of post diversion observations.

We recommend that nutrient diversion continue for Saginaw Bay, as it certainly will. The chief question is how often to monitor the system to insure that water quality is improving, or when it has reached maximum improvement attributable to the action taken. In ecosystems where crops of organisms oscillate by season and over decades it is not a simple task to examine data on a host of species only three years and reach a conclusion.

The rotifers appear to be excellent indicators of water quality. We have found that the indices called "total rotifers (#/ℓ)" and "predatory rotifers (#/ℓ)" seem to be good indicators of water quality. The traditional eutrophic zooplankter "Bosmina" did not behave as expected in Saginaw Bay. We recommend that the EPA select a limited number of water quality objectives within each trophic level in order to limit funds spent on surveillance. Those we have chosen for the zooplankton are presented as examples which are functional.

Sampling intensity in the Saginaw Bay ecosystem should be modified in future years. It appears sufficient to make about 10 cruises each year, with samples from a number of depths with stations in each segment. It does not appear feasible to miss too many years; the gap in data

between 1976 and 1980 made the current investigation difficult to interpret. Likely it will be necessary to sample every other year. The data for phytoplankton and zooplankton should be examined, using ANOVA, to determine optimal sampling schedules.

4. EXPERIMENTAL PROCEDURES

4.1 Sampling and Analytical Methods for Field and Laboratory Collections

Field -- Planktonic crustaceans (cladocerans, copepods) and rotifers were collected during survey cruises on Saginaw Bay, Lake Huron (Figure 1). Approximately 37 stations were sampled at 5 m intervals (1, 5, 10, 15m and bottom), for a total of about 60 samples per cruise. Samples were collected aboard the R.V. Bluewater by University of Minnesota personnel with the help of technicians from the Cranbrook Institute of Science. Cruises of five days duration occured each month from April through November 1980 (Table 1).

Samples to be counted for rotifers were collected with an electric pump (Jabsco Model 11810). Approximately 100 L of water was pumped through a plankton funnel (Likens and Gilbert, 1970) fitted with 54 m nitex nylon screening. Rotifers were relaxed with carbonated water and preserved in 5 percent buffered formalin.

Laboratory -- The crustaceans were enumerated by University of Minnesota Junior Scientist David Grismer, stationed at the E.P.A. Large Lakes Research Station at Grosse Ile. Rotifers were counted by Reed Larson a University senior technician hired and trained by the principal investigator and located in the Biological Sciences Center, St. Paul, Minnesota.

Traditional subsampling methods were used. Each concentrated zooplankton sample was adjusted to a constant volume. The sample was then mixed and an alliquot withdrawn with a Hensen-Stemple pipette. The subsample of 10 ml was counted in a gridded dish at 30 to 100x under a Leitz dissecting microscope. This method sufficed for all crustaceans.

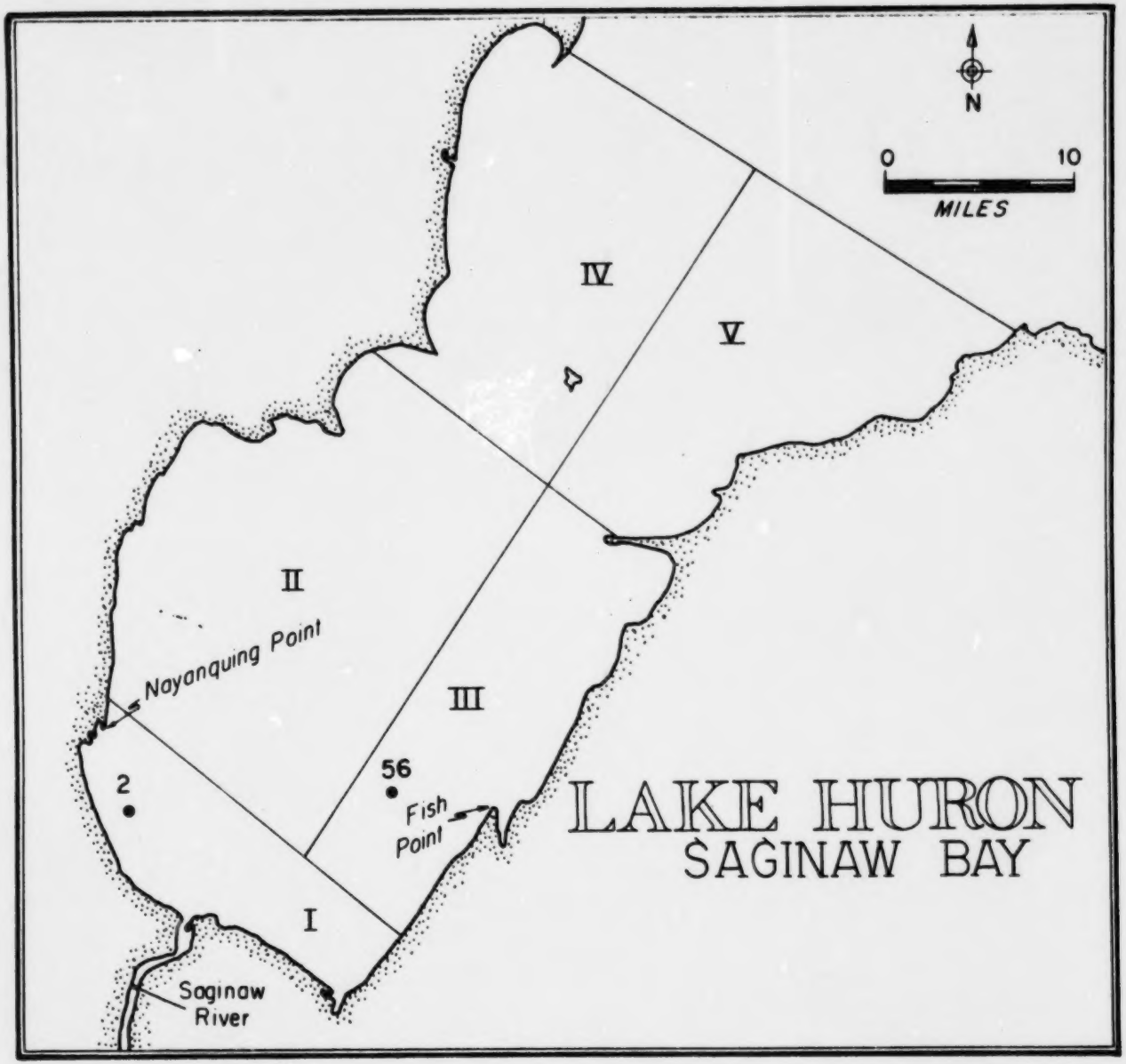

Figure 1. Map of Saginaw Bay study area, showing the five segments of interest.

TABLE 3. Schedule of eight cruises (CIS 84-96) on Saginaw Bay during 1980

Cruise Number	Dates
84	5-9 May
86	26-30 May
88	7-11 July
90	28 July - 1 August
91	18-22 August
92	8-12 September
94	20-22 October
95	10-14 November

Rotifers requiring detailed identification were mounted and examined at 100 or 430x with a compound microscope or settled and counted on an inverted microscope (Nikon). Such detailed counting made possible the narrow confidence limits (one standard error) observed in Figs. 2-12.

Most of the cladocerans were keyed according to Brooks (1959), with the exception of the genera Daphnia (Brooks, 1957), Bosmina and Eubosmina (Deevey and Deevey, 1971) and the family Chydoridae. Adult calanoid and cyclopoid copepods were identified to species according to Wilson (1959) and Yeatman (1959). Calanoid and cyclopod copepedids were handled as separate groups. Rotifers were keyed according to Stemberger, et al. (1979).

5. RESULTS AND DISCUSSION

5.1 Circulation and Response Times for Growth of Zooplankton Populations.

The net circulation pattern in Saginaw Bay in counterclockwise, with Lake Huron water flowing past Tawas into the bay along the northwest shore. After flowing past segments 4 and 2 (Fig. 1), these relatively unperturbed waters mix in segment 1 with the outflow of the Saginaw River. These modified and enriched water masses then exit the Bay, moving along the southeastern shore through segments 3 and 5.

Our first analysis addressed the question of whether crustacean and rotiferan populations can respond to nutrients resuspended during storms (in Segment 4 and 2) or entering via tributaries, so that standing crops are larger in water masses in the exiting waters along the southeastern shore (Segments 3 and 5), as compared to inflowing, open lake waters (segments 4, 2, and 1). This question was examined for a) total crustaceans, b) total cladocerans, c) Bosmina longirostris, d) total rotifers, e) eutrophic rotifers, and f) predatory rotifers.

The response of crustacean populations to transportation through Saginaw Bay was consistent by group and by season. Considering first the total crustacean population (Fig. 2), we see that during the spring pulse of zooplankton in 1974 (Julian Day 171), about 400/ℓ entered the Bay; these populations had increased approximately 50% in their 1 day passage around the Bay, and about 600/ℓ left the Bay around the Thumb. During 1975, all crustacean populations were inhibited; numbers entering the Bay during the spring pulse (Julian Day 542) were greater than those leaving; i.e., a net mortality occurred within the Bay. In the fall of 1975 (Julian Day 648) zooplankton crustaceans had tripled their numbers as they journied around the Bay and exited at segment 5.

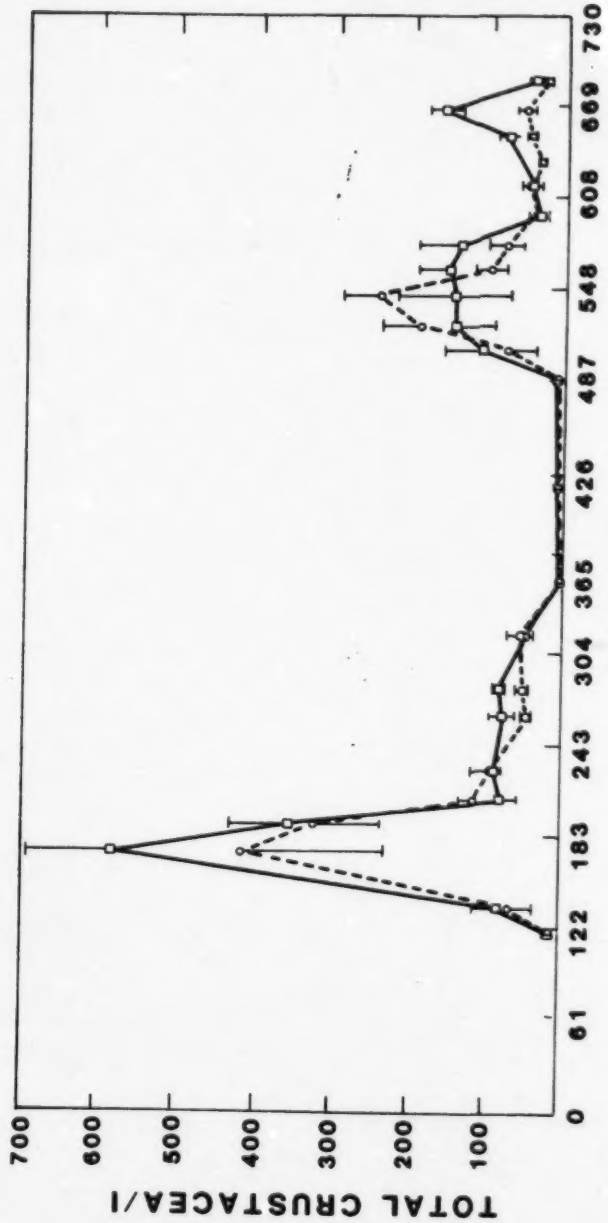

Figure 2. Comparison of total crustacea (#/ℓ) entering Saginaw Bay by Segments 2 and 4 (○) with those exiting the Bay by Segments 3 and 5 (□) during 1974 and 1975.

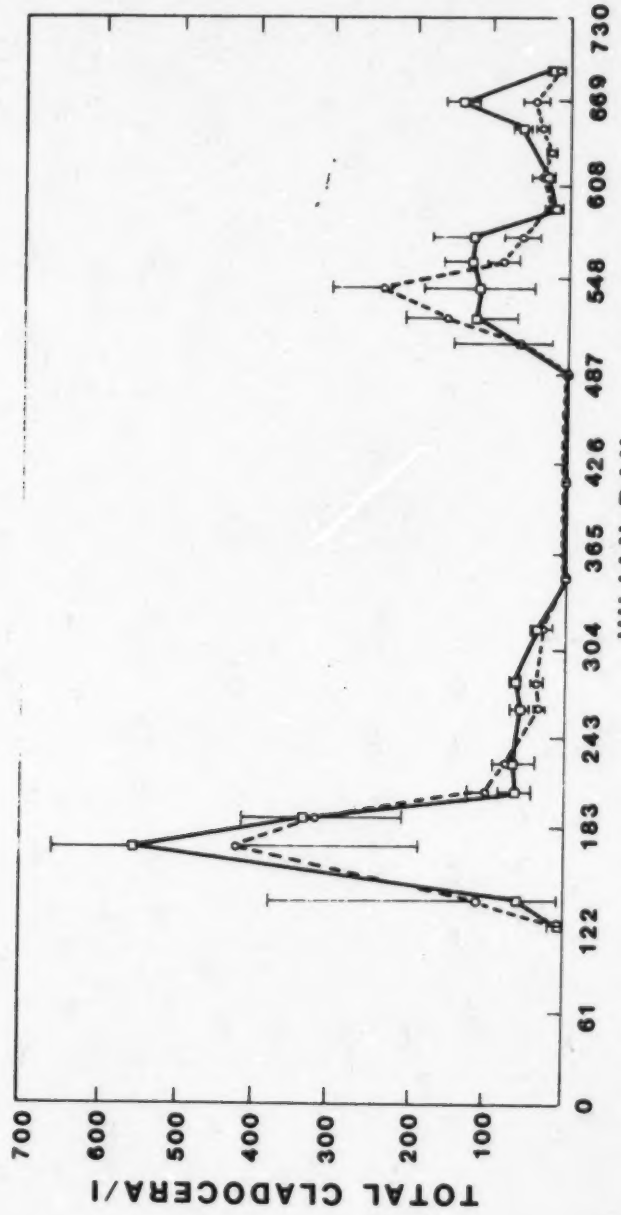

Figure 3. Comparison of total Cladocera (#/ℓ) entering Saginaw Bay by Segments 2 and 4 (○) with those exiting the Bay by Segments 3 and 5 (□) during 1974 and 1975.

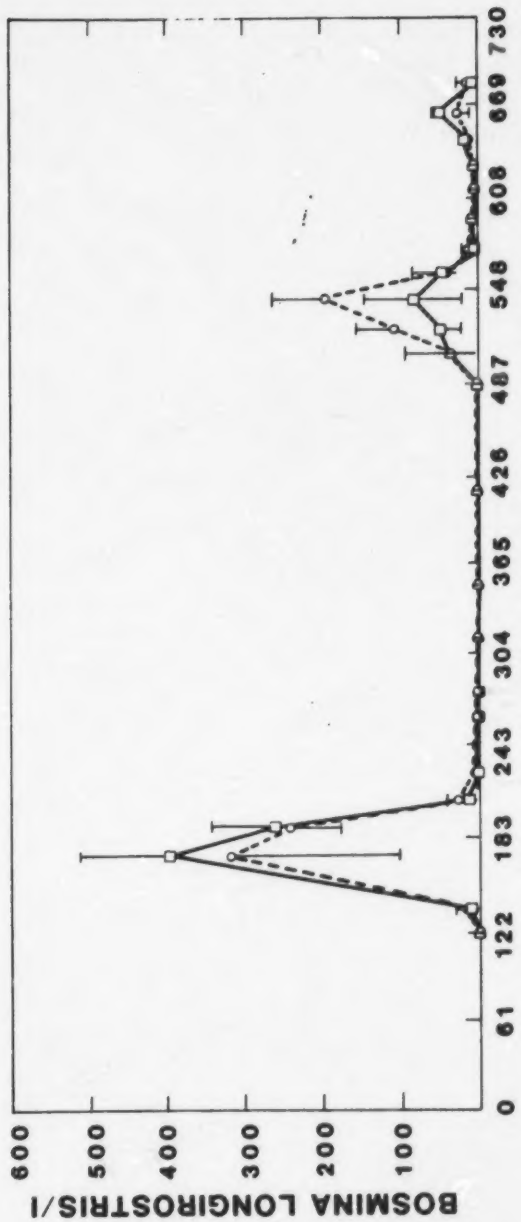

Figure 4. Comparison of Bosmina longirostris (#/ℓ) entering Saginaw Bay by Segments 2 and 4 (○) with those exiting the Bay by Segments 3 and 5 (□) during 1974 and 1975.

The pattern of growth and the resultant standing crops (#/ℓ) of total cladocera and Bosmina longirostris mirror the results for total crustacea, because Bosmina (Fig. 4) comprised the bulk of the Cladocerans (Fig. 3) found in the Bay in 1974 and 1975.

5.2 Responses of Crustacean Populations to Nutrient Diversion

The zooplankton community of Saginaw Bay was dominated during the pre-diversion years of 1974-75 by the cladoceran Bosmina longirostris which reached densities of 600,000/m^3 during June. Bosmina l. is considered an eutrophic indicator. The predominate calanoids were Diaptomus minutus and D. ashlandi, also eutrophic indicators. However, healthy populations of the oligotrophic form Diaptomus sicilis (1,200/m^3) were found during April 1975 in Section II (Gannon and Bricker, unpublished).

Diversion of 50% of phosphorus in 1978 permitted the large scale ecosystem experiment the EPA team set out to conduct. Results of diversion upon the total crustacean community, the cladocerans, and the eutrophic indicator Bosmina, were similar, since Bosmina constituted 24-38% of the crustacean community.

Total crustaceans were most abundant in 1974 (155708/m^3), fell by 46% in 1975 (83977/m^3) and remained low in 1980 (97825/m^3) (Figure 5). This general pattern (Table 4), based on monthly mean densities from April through December, suggested that 1975 was either an unusual year, or the causal relationship between nutrient diversion and zooplankton growth was not obvious. We will illustrate under section (5.4) entitled "Ecological Interpretations" that 1975 was an unusual year, and that comparisons between 1974 and 1980 likely represent pre- and post-diversion conditions.

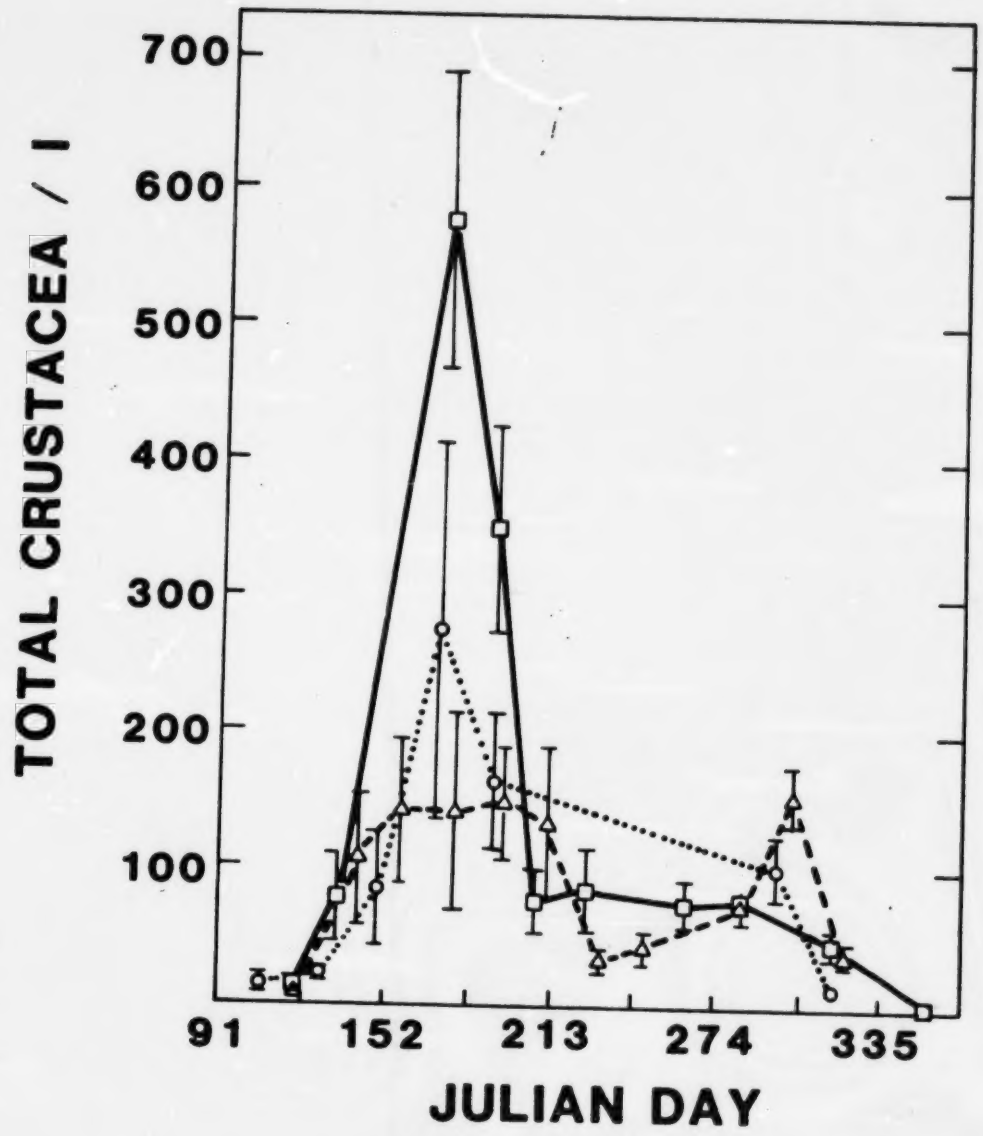

Figure 5. Numbers of crustaceans (#/ℓ) found in Segments 3 and 5 during 1974 (□), 1975 (△) and 1980 (○).

Table 4. Total crustaceans in outflowing waters of Saginaw Bay (Segments 3 and 5) by weighted monthly means and yearly mean ($\#/m^3$).

Month	Arithmetic Mean and Standard Error		
	1974	1975	1980
April	11540 ± 2410	7300 ± 1600	9810 ± 3370
May	70600 ± 18030	89350 ± 26790	19250 ± 3630 58510 ± 13980 38880
June	529690 ± 59580	134640 ± 36660 112510 ± 32890 123575	275180 ± 138480
July	322190 ± 44220 65100 ± 10810 193645	149180 ± 36080 107180 ± 23630 128180	143160 ± 25480
August	85760 ± 25270	32670 ± 7420	88270 ± 24310
September	59790 ± 10350	37310 ± 5540	
October	79600 ± 6450	74090 ± 10350 154500 ± 19110 114295	104200 ± 26420
November	49170 ± 11940	41160 ± 9830	15720 ± 2860
December	2390 ± 1670		
Yearly Mean (weighted for A, M, J, J, O, N)	155708.	83977.	96460.

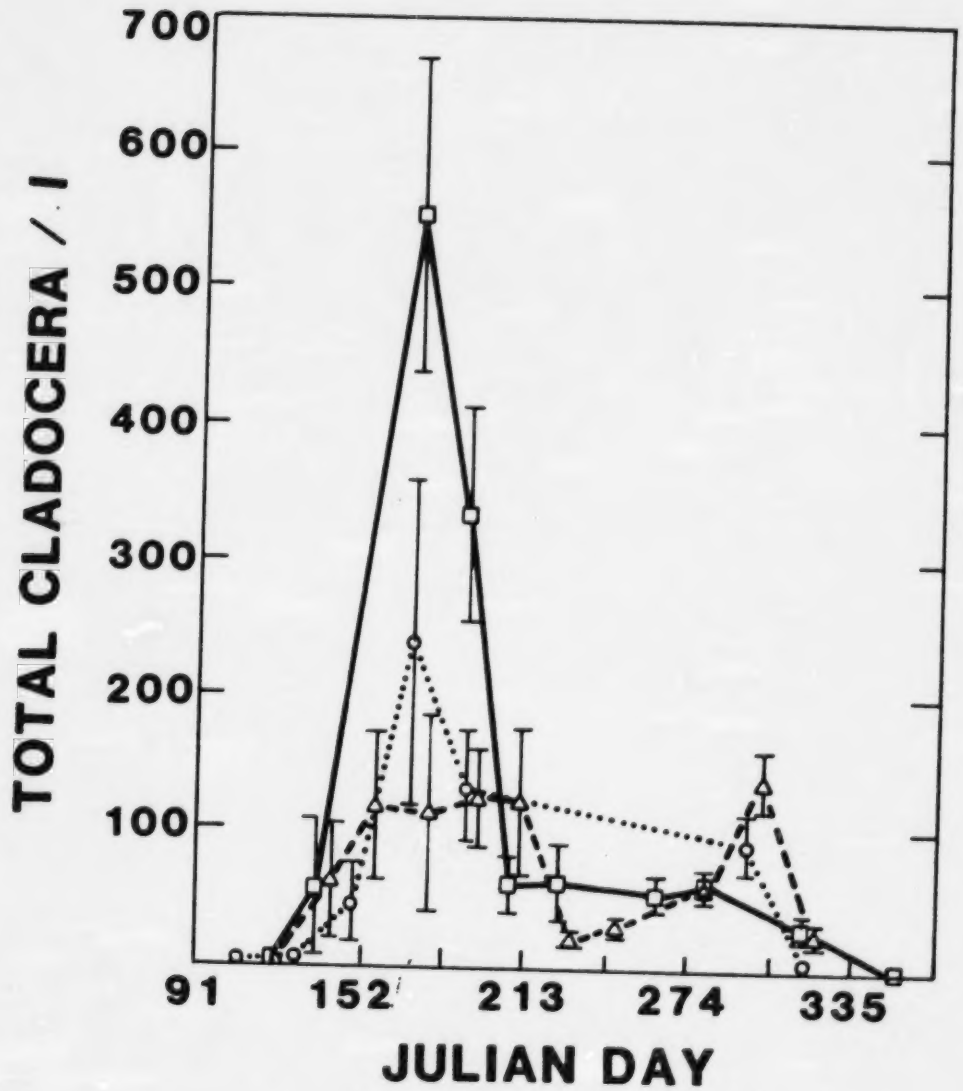

Figure 6. Numbers of cladocerans (#/ℓ) found in Segments 3 and 5 during 1974 (□), 1975 (Δ) and 1980 (○).

Table 5. Eutrophic Indicator Bosmina longirostris: abundance in outflowing waters of Saginaw Bay (Segments 3 & 5) by weighted monthly means and yearly mean (#/m^3).

Month	Arithmetic Mean and Standard Error		
	1974	1975	1980
April	230 ± 50	120 ± 40	610 ± 320
May	6050 ± 1770	26060 ± 10480	1020 ± 280 21690 ± 8880 11355.
June	328780 ± 48820	37860 ± 13460 59470 ± 25660 48665	102330 ± 35670
July	210770 ± 32670 10610 ± 2610 16190	18790 ± 6160 2860 ± 1980 10825	42210 ± 10060
August	1780 ± 340	3900 ± 1510	3000 ± 1020
September	1050 ± 320	830 ± 150	
October	1340 ± 230	15310 ± 3490 47350 ± 8960 31330	65670 ± 12950
November	1750 ± 470	6830 ± 2380	490 ± 130
December	20 ± 10		
Yearly Mean (weighted for A, M, J, J, O, N)	59056.	20638.	32237.
Bosmina as % of total crustaceans	37.9	24.6	33.4

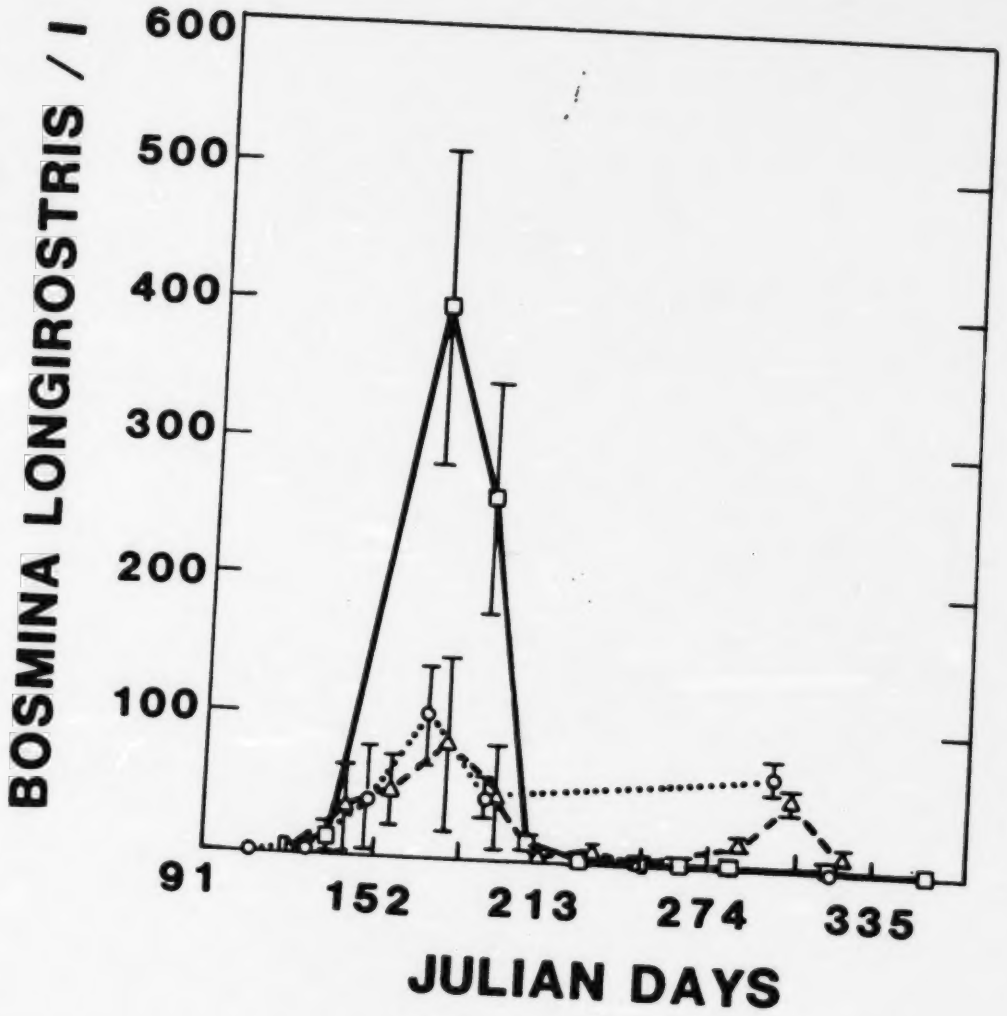

Figure 7. Numbers of Bosmina longirostris (#/ℓ) found in Segments 3 and 5 during 1974 (□), 1975 (Δ) and 1980 (○).

Decreases in Total Cladocera, 1974 versus 1980.

The Cladocera are the best indicators of eutrophication. Generally they are small zooplankters, even though they are able to feed on large algal cells. For example, the cladoceran Chydorus sphaericus is the most effective grazer in the Great Lakes, even though it is among the smallest cladocerans (McNaught et al., 1981).

It is not worthwhile to break the cladocerans into their specific components, because Bosmina is so dominant in the Bay that it provides almost their total biomass.

The spring peak of cladocerans was significantly higher in 1974 than in 1975 and 1980. Generally summertime and fall populations were not significantly different (Figure 6).

Decreases in Bosmina longirostris, 1974 versus 1980

Most cladocerans in Saginaw Bay are the eutrophic indicator Bosmina longirostris. During the spring peak in 1974 we observed 378,780/m^3; these peak populations dropped to 102,330/m^3 in 1980, a decrease of 3.2 times (Table 5). Thus, the magnitude of spring blooms of Bosmina is evidence for decreased eutrophication of Saginaw Bay following diversion of sewage if the 1975 data can be explained (Figure 7).

Two opposing indicators, Diaptomus ashlandi and D. sicilis.

Diaptomus ashlandi is a eutrophic diaptomid, found for example in the waters of Lake Ontario off of productive Bay of Quinte (McNaught and Buzzard, 1973). In sharp contrast, Diaptomus sicilis is characteristic of cold oligotrophic waters, is not usually found above 11°C (McNaught and Hasler, 1966), and predominates in oligotrophic Lake Superior (Watson, 1974). Neither calanoid is common in Saginaw Bay; however, we wanted to examine trends in their density from 1974 through 1980.

Generally the numbers of Diaptomus ashlandi and D. sicilis did not change significantly from 1974 through 1980 (Figures 8, 9).

Diaptomus ashlandi had a minimum abundance of 325/m^3 in 1974 and increased to a maximum of 925/m^3 in 1980. This 3 fold increase in the density of the spring bloom (Figure 8) could be interpreted as evidence of increasing eutrophication.

Diaptomus sicilis was slightly but not significantly more common in the spring of 1980 than in 1974 (Figure 9). This change if significant would have been evidence for decreased eutrophication and the recovery of water quality in Saginaw Bay. The lack of statistical differences make either potential conclusion weak, and we will not make other ones based simply on abundances of these rare forms.

5.3 Responses of Rotifer Populations to Nutrient Diversion

Three basic indices will be utilized to examine the impact of nutrient diversion upon the rotifer populations of Saginaw Bay, including:

a) the total density (#/m^3) of rotifers in 1974 and 1980,

b) the density of eutrophic indicators (all Brachionus spp.), and

c) the density of predatory rotifers.

Total Density of Rotifers, 1974 versus 1980.

Rotifers are abundant in many aquatic ecosystems. In Saginaw Bay, they outnumber (1,115,000/m^3 in 1974) the crustacean zooplankton (156,000/m^3 in 1974) on a mean yearly basis. The results of this study suggest that the total rotifer community, as well as some of its components, are useful indices to the effects of nutrient diversion from a eutrophic ecosystem.

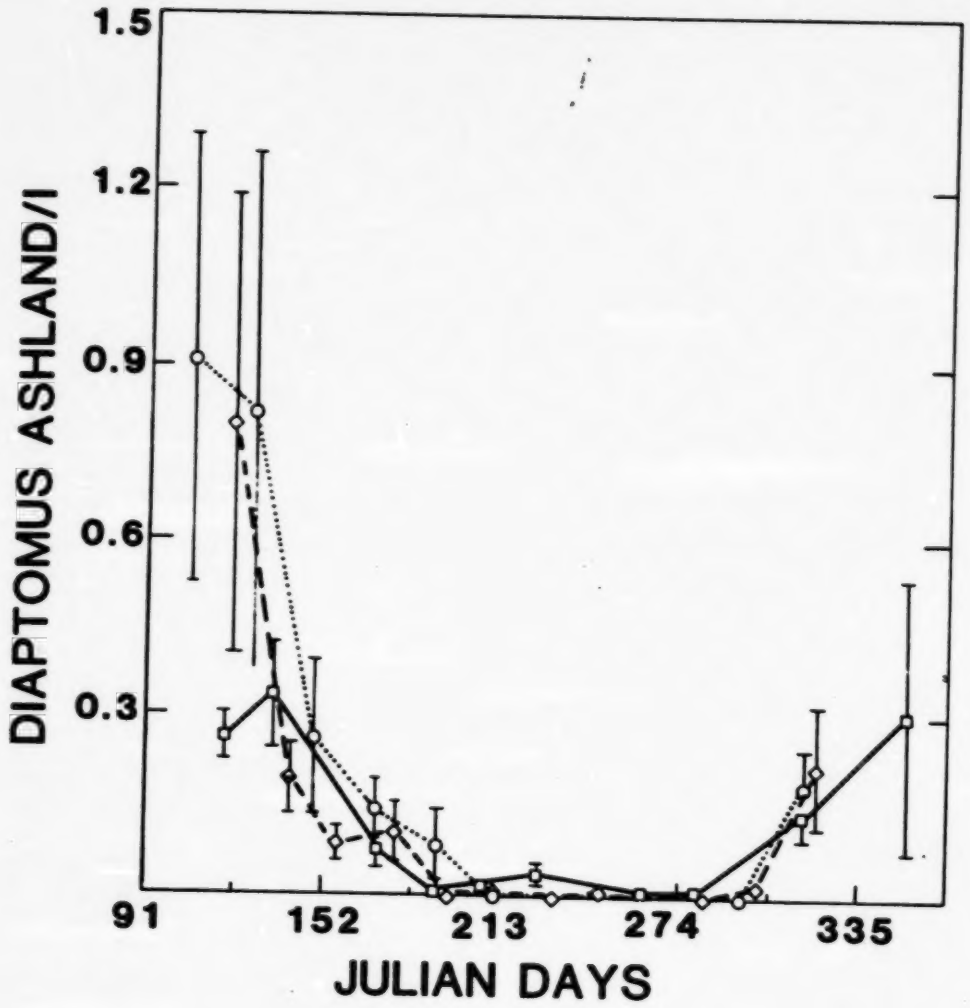

Figure 8. Numbers of eutrophic Diaptomus ashlandi (#/ℓ) found in Segments 3 and 5 in 1974 (□), 1975 (◇) and 1980 (○).

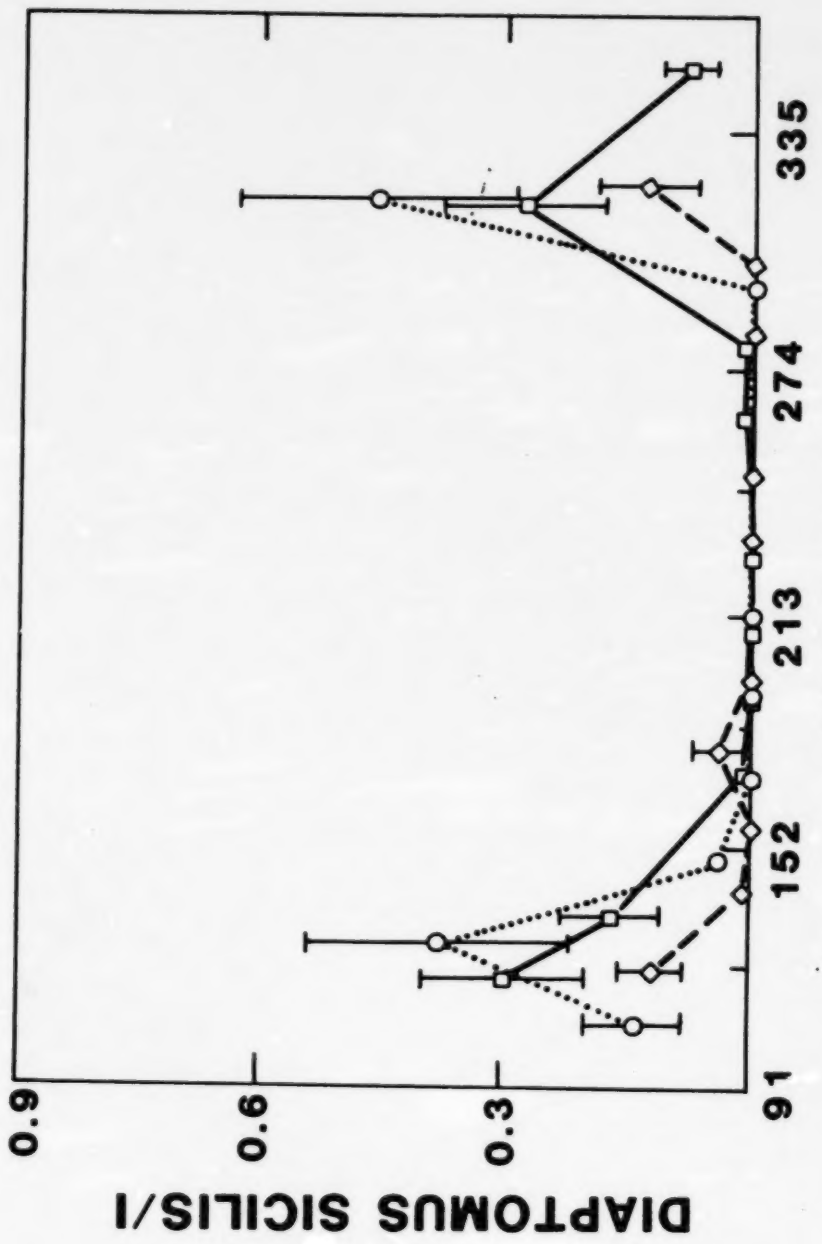

Figure 9. Numbers of oligotrophic Diaptomus sicilis (#/ℓ) found in Segments 3 and 5 in 1974 (□), 1975 (◇) and 1980 (○).

Density of Total Rotifers, 1974-80.

The total rotifer community ranged in density from 600,000/m^3 to 1,400,000/m^3 in 1974. The population curve was roughly unimodal, with the midsummer peak occuring on Julian day 190. This unimodal growth curve for rotifers is an initial indication that the spring peak in nannoplankton production and the warm temperatures of midsummer account for much of the relatively high summer long productivity of rotifers during 1974. When nutrients were diverted in 1978 and thereafter, high numbers were observed during 1980 only on Julian day 191 (Figure 10). This is a dramatic reduction in total numbers attributed to nutrient division (Table 6).

Density of Eutrophic Rotiferan Indicators, 1974 versus 1980

The rotifers of the genus Brachionus (8 spp. in Saginaw Bay, along with the very rare genus, Anuraeopsis, which was absent during 1980, have been used as indicators of eutrophication. We anticipated that these dutrophic indicating rotifers would be more common during 1974 than during 1980 (Figure 11).

The results of the eutrophic rotifer comparison (Figure 11) show that these indicators were more common on four early dates (between Julian day 91 and 213) in 1974 than in 1980. However, in the late summer and early fall (Julian days 213 to 304) these eutrophic indicators were more prevalent in 1980.

No significant difference is evident with one standard error in Figure 11 between 1974 and 1980 populations of eutrophic rotifers. We conclude that the eutrophic indicator Brachionus (since Anuraeopsis did not occur in 1980) has not responded to the drop in nutrient levels which occurred during this period, nor to changes in phytoplankton

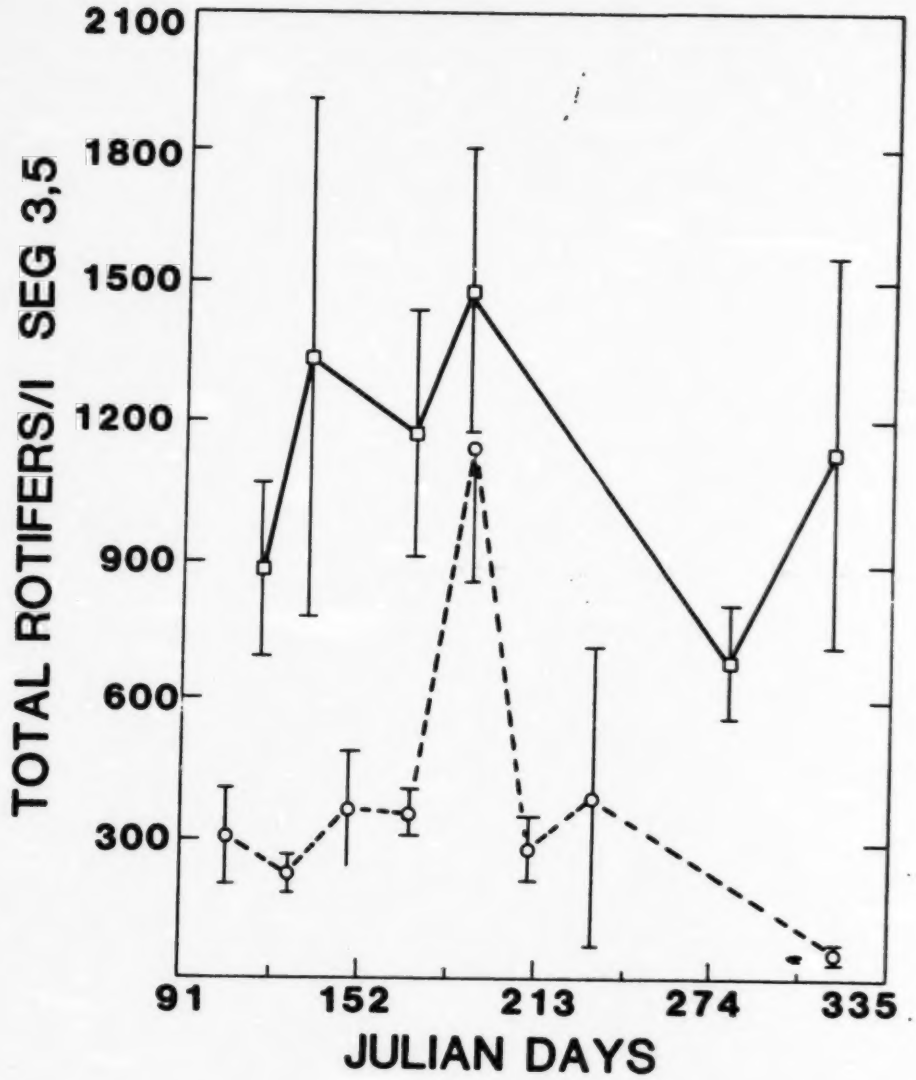

Figure 10. Numbers of rotifers (#/ℓ) found in Segments 3 and 5 in 1974 (□) contrasted to 1980 (○).

Table 6. Total rotifers (#/m^3) by monthly mean for 1974 and 1980 in Saginaw Bay (Segments 3, 5).

Month	Mean and Standard Error	
	1974	1980
April	876700 ± 188620	304830 ± 103610
May	1332860 ± 559560	225700 ± 40960
		365290 ± 123300
		295495
June	1170510 ± 265310	354350 ± 49850
July	1476610 ± 305990	1142090 ± 291220
		279260 ± 68690
		710675
August		389190 ± 320780
October	680760 ± 119340	57980 ± 18960
November	1129930 ± 420720	
Monthly Mean	1114562/m^3	352087.

$$\frac{1114562\ (1974)}{352087} = 3.16 \text{ fold reduction}$$

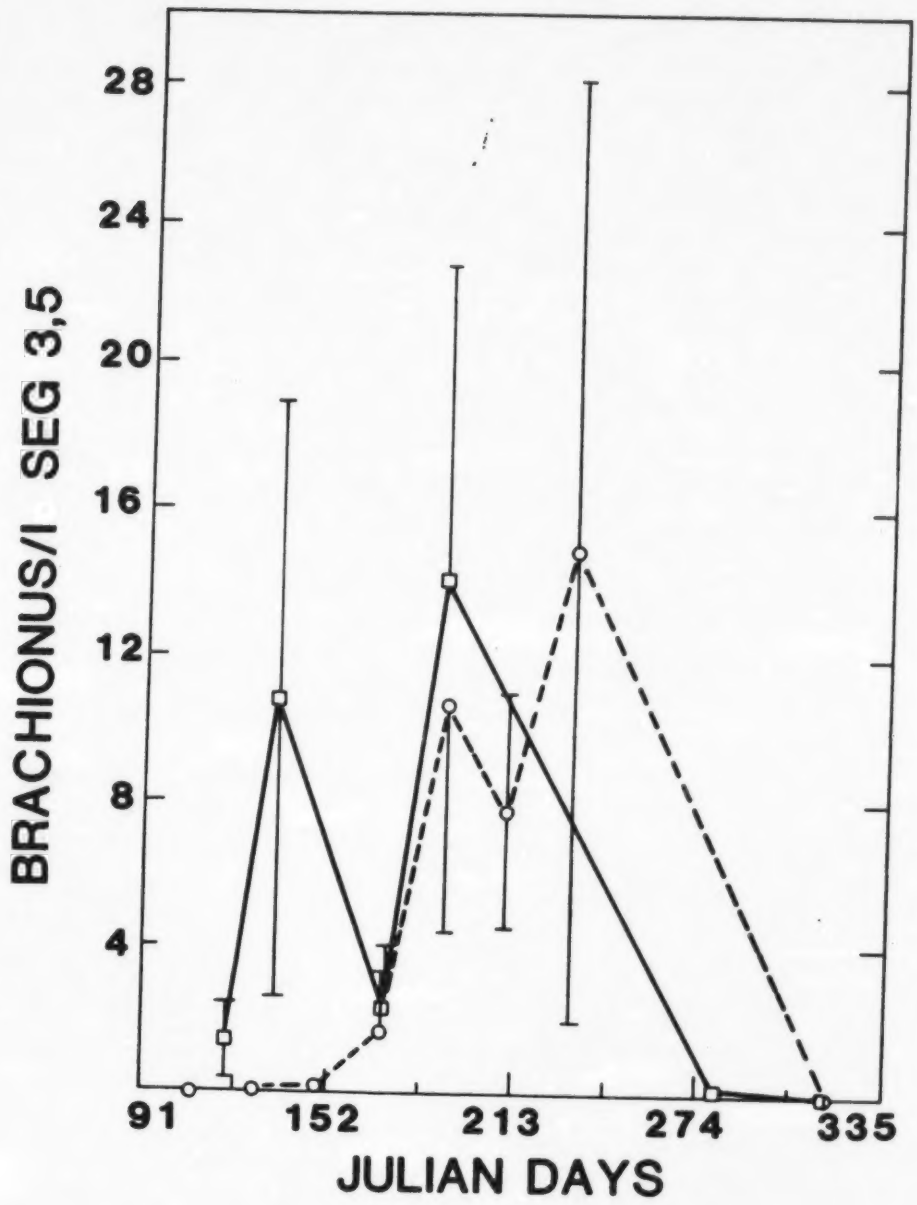

Figure 11. Numbers of eutrophic rotifers Brachionus and Anuraeopsis (#/ℓ) found in Segments 3 and 5 in 1974 (□) contrasted to 1980 (○).

populations. Generally Brachionus has not responded to what is clearly reduced trophy, likely because its food resources including detritus have not dropped significantly in the Bay.

Density of Predatory Rotifers, 1974 versus 1980

Normally the predators in a community, whether terrestrial or aquatic, show a marked response to changes in lower trophic levels. There are many famous examples of closely linked predator-prey cycles, the most famous and well documented being the lynx-hare cycle in the Canadian arctic.

We hypothesized that decreases in trophy would clearly result in decreases in predatory rotifer populations (Table 6). We attempted to identify all significant predatory rotifers in Saginaw Bay, including the following genera (selected by J. Gannon, pers. comm. 1982):

Ploesoma (3 spp.)
Colophaeca (2 spp.)
Stephanocercos
Trichocerca (all)
Gastropis
Polyarthra (4 spp.)
Asplachna (5 spp.)

As hypothesized, predatory rotifers exhibited a significant decrease between 1974 and 1980 (Figure 12). On six of seven dates in 1980 these apex organisms were less common than during 1974. We conclude that predatory rotifers constitute significant evidence that Saginaw Bay is rapidly reponding to decreased loadings of phosphate and nitrate.

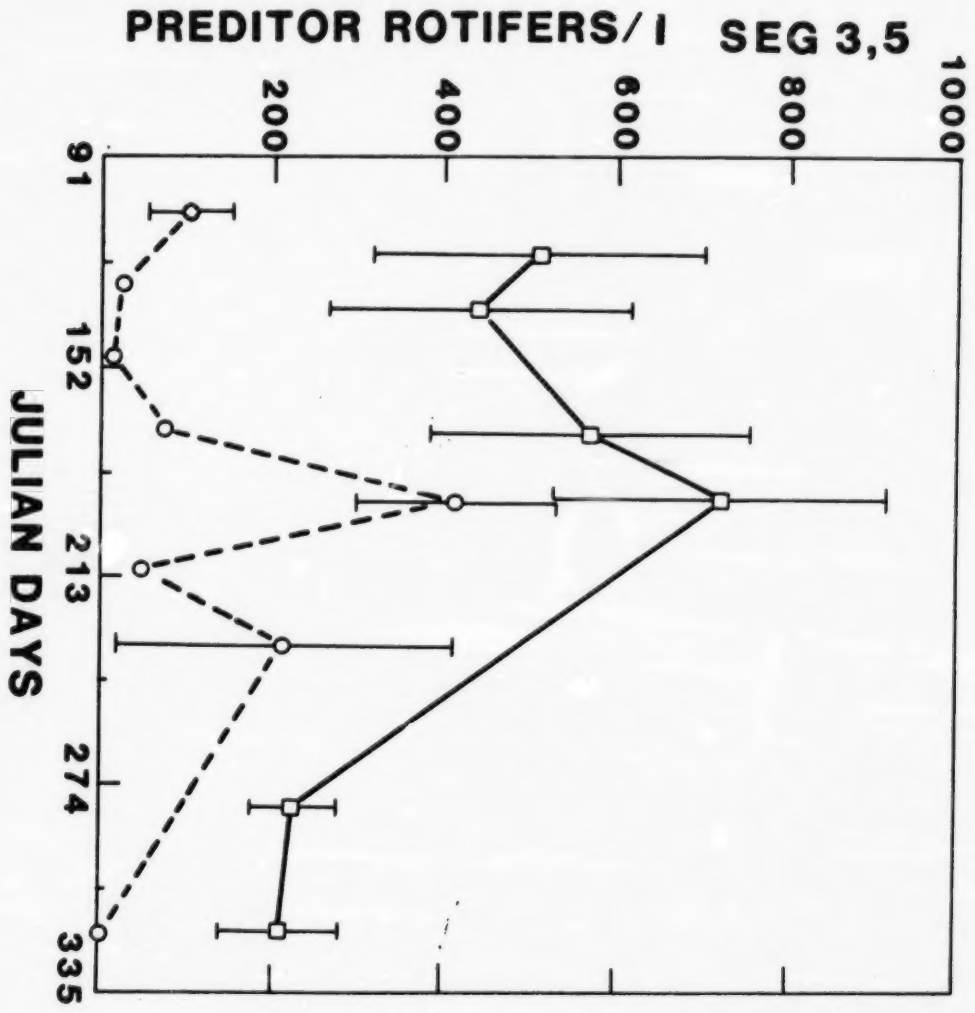

Figure 12. Numbers of predatory rotifers (more than 14 species in 7 genera) in Saginaw Bay (#/ℓ) in Segments 3 and 5 in 1974 (□) contrasted to 1980 (○).

5.4 Ecological Interpretations

Interpreting Saginaw Bay as an Integrator of Nutrient Inputs: Different Seasonal Patterns in 1974 for Crustaceans

During springtime 1974 the crustacean populations leaving the Bay were larger than those entering, whereas in the fall they were smaller. What related factors involving nutrients and phytoplankton abundance might explain this pattern?

Nutrient inputs to Saginaw Bay are known to differ between seasons (Figure 13). During the springtime of 1974 heavy runoff in the Saginaw River drainage basin brought an influx of phosphate into the Bay (Figure 14). Phytoplankton populations prospered during the springtime, the more edible diatoms and green algae were abundant. Springtime algal populations were driven by the high springtime phosphate levels of 25 $\mu g\ \ell^{-1}$; these phosphate levels remained relatively high all summer around 5 $\mu g\ \ell^{-1}$, but dropped to 4 $\mu g\ \ell^{-1}$ in October, with the absence of a fall influx of nutrients in 1974 (Figures 13, 14). Phosphate levels in September through December were about 4 $\mu g\ \ell^{-1}$. Thus high phosphate levels during springtime account for good growth of diatoms and green algae and their crustacean grazers.

Different Yearly Patterns for crustaceans

During 1974 and 1975 crustaceans (Table 4) varied greatly in abundance. Since these were "control" years, an understanding of the underlying mechanism responsible for these differences is vital.

As explained in our detailed analysis of phosphate, phytoplankton and nutrient dynamics for 1974, the critical factor was the spring

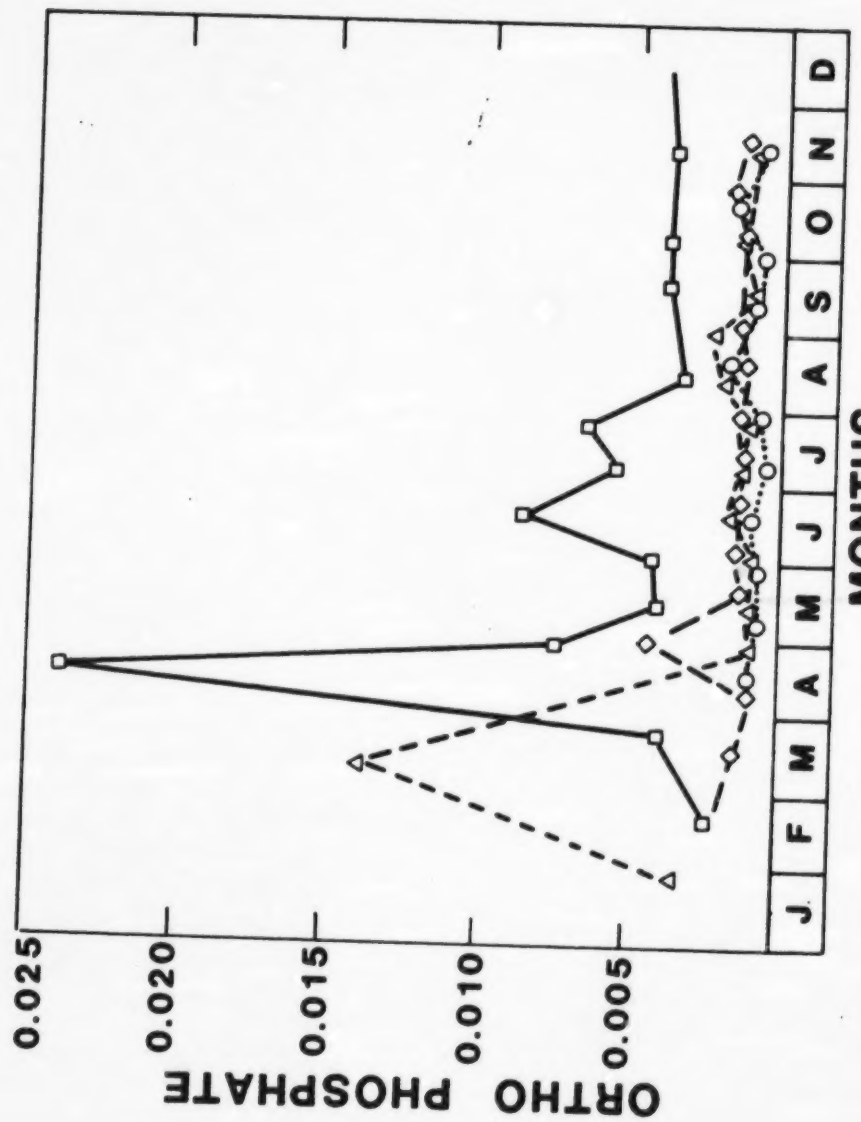

Figure 13. Concentration of orthophosphate (µg/ℓ) in Segments 3 and 5 in 1974 (□), 1975 (△) and 1980 (○).

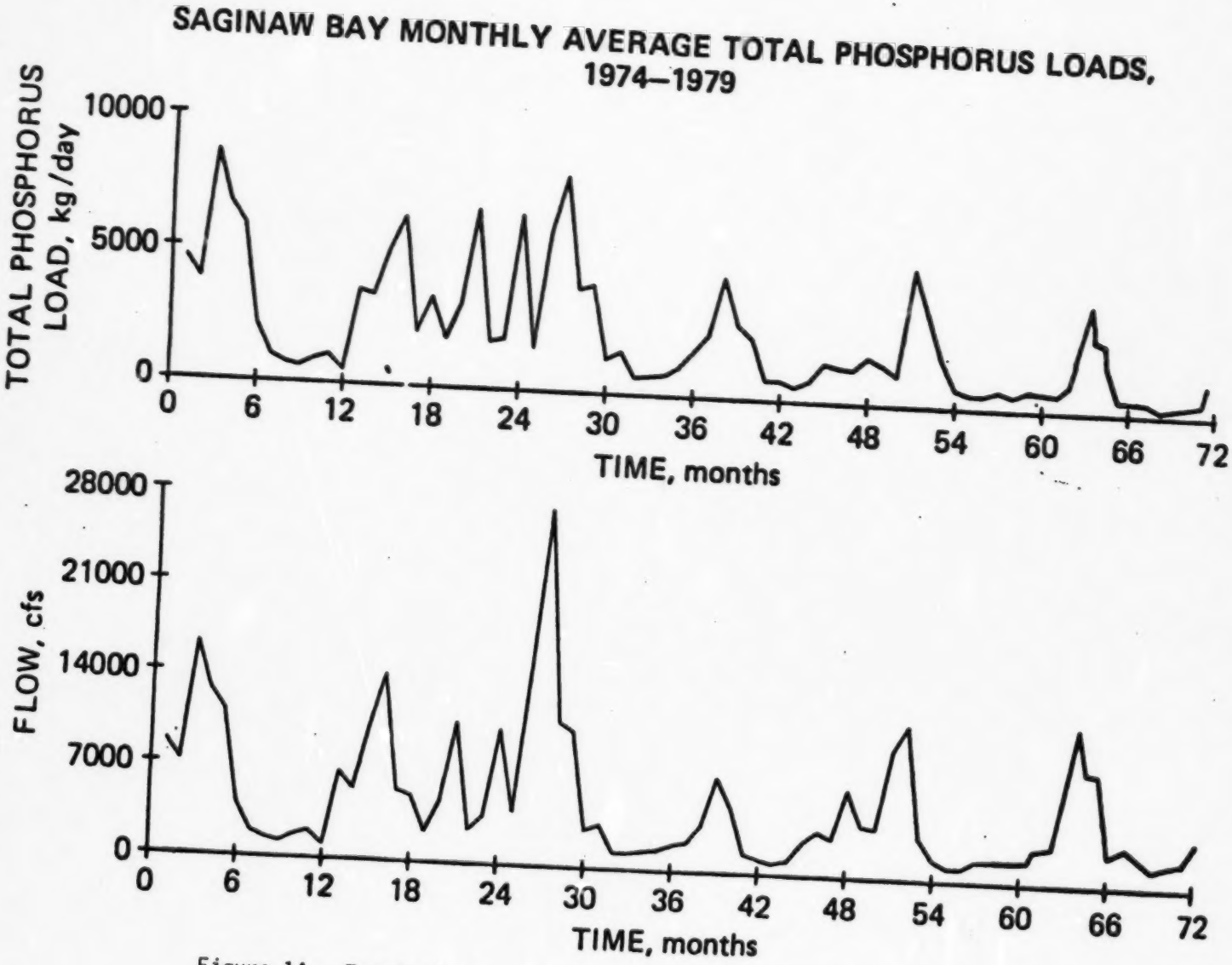

Figure 14. Total phosphorus with respect to flow (cfs) for Saginaw Bay, 1974-1979.

influx of phosphate due to a thorough flushing of the Saginaw River drainage basin (Figure 14). This abundant nutrient supply led to a high production of diatoms and green algae.

During 1975 the springtime rains were less, directly effecting inflow of runoff waters and phosphorus (Figure 14, month 15), and much of the flow and resultant phosphorus loading took place later in the summertime (Figure 14, month 20), when less edible blue-green algae were abundant, but able to exist on recycled nutrients.

Interpretation of Changing Crustacean Populations

The major chemical variable, which drives phytoplankton populations as well as correlates with zooplankton production, was dissolved ortho-phosphate (Figure 13).

Phosphate is recycled or released from bottom muds during summertime (Bierman and Dolan, 1971) but enters Saginaw Bay via surface rains and river systems during spring and fall. Obviously orthophosphate levels in 1974 (Figure 13) were high. The spring peak was twice that in 1976 and five times that in 1975. If nutrients drive the Saginaw Bay ecosystem, then phosphate levels alone may predict zooplankton production. In 1980 phosphate was also low from April through December. Thus in the years for which zooplankton data and nutrient data are available, standing crops of orthophosphate closely predict zooplankton levels. These nutrient data suggest a close linkage between phosphorus, phytoplankton production, and zooplankton composition and standing crop.

In contrast to ortho-phosphate, available nitrate levels were high in the spring and low from June through October. But more importantly, nitrate levels did not vary in Saginaw Bay in 1974, 75 and 1980. In contrast to phosphate, much of the nitrate may result from the fixation

of elemental Na by the blue-green algae, which continue to be prevalent in the Bay (Figure 15).

We conclude that high phosphate levels from 1974 through 1978 were correlated with observed standing crops of crustacean zooplankton dominated by Bosmina. A 50% reduction in the loading of phosphorus, but a reduction in the water from 31.6 to only 24.0 $\mu g\ \ell^{-1}$, (Table 7) led to the small changes in crustacean populations and the very significant decreases in total rotifers and predatory rotifers observed.

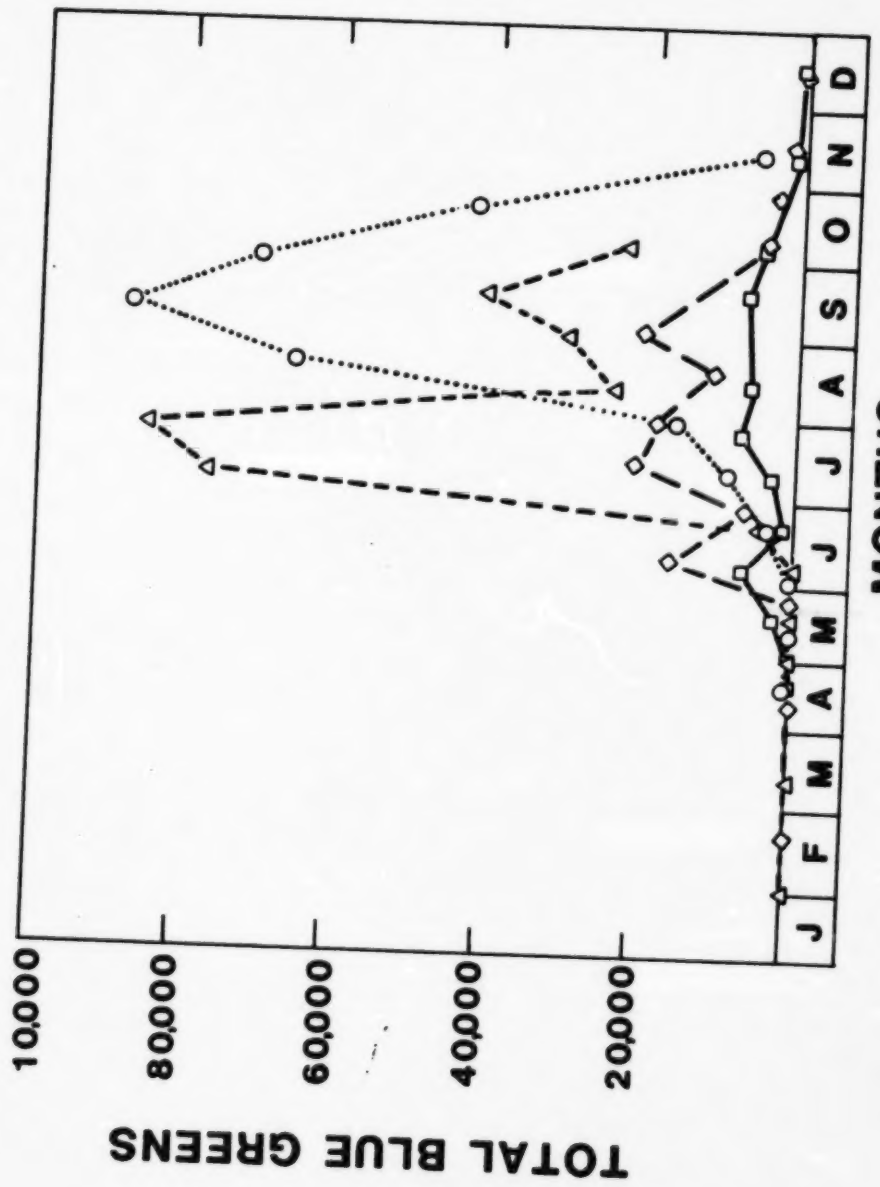

Figure 15. Total bluegreen algae for the years 1974 (□), 1975 (◇), 1976 (△) and 1980 (○).

TABLE 7. Loading of phosphorus versus zooplankton composition in Saginaw Bay during 1974, 1975, 1978, and 1980.

	Year			
	1974	1975	1978	1980
Nutrient Loading and Concentration*				
Fluvial Inputs				
Fluvial - total riverine	1,345	1,575	-	-
(Saginaw River)	(1,266)	(1,472)	(-)	(-)
Total Input	1,416	1,645	800?	800?
Concentration				
Bay water ($\mu g\ L^{-1}$)	31.6	-	29.0	24.0
Zooplankton Dominance				
Cladocerans	Bosmina** longirostris	Bosmina** longirostris		Bosmina*** longirostris
Calanoid copepods	Diaptomus** minutus	Diaptomus** ashlandi		Diaptomus*** sicilis?
Rotifera	Total density high ($1,114,500/m^3$)			Total density low ($352,000/m^3$)

*From Dolan and Clark, 1980 and Smith et al. 1977.

From Gannon and Bricher (unpublished) and this report*

6. LITERATURE CITED

Bierman, V.J., Jr., and D.M. Dolan. 1981. Modeling of phytoplankton-nutrient dynamics in Saginaw Bay, Lake Huron. J. Great Lakes Res. (7) 409-439.

Brooks, J.L. 1957. The Systematics of North American Daphnia. Mem. Connecticut Acad. Arts and Sciences. Vol. 13. pp. 1-180.

Brooks, J.L. 1959. Cladocera. Ch. 27 in Fresh-water Biology. Ed. by W.T. Edmondson. John Wiley, New York. pp. 587-656.

Comita, G. and Anderson. 1959. The seasonal development of a population of Diaptomus ashlandi Marsh, and related phytoplankton in Lake Washington. Limnol. Oceanogr. 4:37-52.

Deevey, E.S. and G.B. Deevey. 1971. The American species of Eubosmina Seligo (Crustacea, Cladocera). Limnol. Oceanogr. 16:219-240.

Dolan, D. and J. Clark. 1979. Modeling the total phosphorus reduction in Saginaw Bay, 1974-78. Presented at Int. Conf. Great Lakes Res., 1979 (unpublished).

Gannon, J.E. and K.S. Bricker. 1978. Crustaceans in Saginaw Bay (unpublished).

Edmondson, W.T. 1969. Eutrophication in North America. In Eutrophication: Causes, Consequence, Correctives. Nat. Acad. Sci., Washington, D.C. pp. 124-149.

Jaworsky, N.A. 1979. Sources of nutrients and the scale of eutrophication problems in estuaries. Presented at Int. Symp. on Effects of Nutrient Enrichment in Estuaries.

Likens, G.E. and J.J. Gilbert. 1979. Notes on quantitative sampling of Natural populations of planktonic rotifers. Limnol. and Oceanogr. 15:816-820.

Likens, G.E. and O.L. Loucks. 1978. Analysis of five North American lake ecosystems. III. Sources, loading and fate of nitrogen and phosphorus. Ver. Int. Verein. Limnol. 20:256-273.

McNaught, D.C. and A.D. Hasler. 1966. Photoenvironments of planktonic crustacea in Lake Michigan. Verh. Int. Ver. Limnol. 16:194-203.

McNaught, D.C. and M. Buzzard. 1973. Changes in zooplankton community structure in Lake Ontario (1939-72). Proc. 16th Conf. Great Lakes Res. 1973:76-86.

McNaught, D.C. 1975. A hypothesis to explain the succession from calanoids to cladocerans during eutrophication. Ver. Int. Verein. Limnol. 19:724-731.

McNaught, D.C., M. Buzzard, D. Griesmer and M. Kennedy. 1981. Inhibition of productivity by PCBs and natural products in Saginaw Bay, Lake Huron. Ecological Res. Series, U.S.-E.P.A. (in press).

Scheffer, V.B. and R.J. Robinson. 1939. A limnological study of Lake Washington. Ecol. Monogr. 9:95-143.

Smith, V.E., K.W. Lee, J.C. Filkins, K.W. Hartwell, K.R. Rygwelski and J.M. Townsend. 1977. Survey of chemical factors in Saginaw Bay (Lake Huron). Ecological Research Series, EPA 600/3-77-125. Environmental Res. Lab., Duluth, MN 143 pp.

Stemberger, R.S., J.E. Gannon, and F.J. Bricker. 1979. Spatial and seasonal structure of rotifer communities in Lake Huron. Ecological Res. Series, E.P.A. 600/3-79-085. Environmental Res. Lab., Duluth, MN. 159 pp.

Stockner, J.G. and W.W. Benson. 1967. The succession of diatom assemblages in the recent sediments of Lake Washington. Limnol. Oceanogr. 12:513-532.

Watson, N.H.F. 1974. Zooplankton of the St. Lawrence Great Lakes - species composition, distribution, and abundance. J. Fish. Res. Bd. Can. 31(5):783-94.

Wilson, M.S. 1959. Calanoida, Ch. 29 in Fresh-water Biology. Ed. by W.T. Edmondson. John Wiley, New York. pp. 738-794.

Yeatman, H.C. 1959. Cyclopoida, Ch. 29 in Fresh-water Biology. Ed. by W.T. Edmondson. John Wiley, New York. pp. 795-814.